

Review

The role of major histocompatibility complex molecules in luteal function

Matthew J Cannon and Joy L Pate*

Address: Department of Animal Sciences, The Ohio State University/Ohio Agricultural Research and Development Center, 1680 Madison Avenue, Wooster, OH 44691, USA

Email: Matthew J Cannon - cannon.56@osu.edu; Joy L Pate* - pate.1@osu.edu

* Corresponding author

Published: 10 November 2003

Received: 14 April 2003

Reproductive Biology and Endocrinology 2003, **1**:93

Accepted: 10 November 2003

This article is available from: <http://www.rbej.com/content/1/1/93>

© 2003 Cannon and Pate; licensee BioMed Central Ltd. This is an Open Access article: verbatim copying and redistribution of this article are permitted in all media for any purpose, provided this notice is preserved along with the article's original URL.

Introduction

One of the amazing features of the corpus luteum (CL) is the rapidity with which a very heterogeneous population of cells becomes organized into a functional unit. These diverse cells then communicate both directly and through paracrine mediators to facilitate the steroidogenic function and also the transient nature of the CL. Once the hormonal regulators of luteal function and demise (for example, LH and prostaglandin $F_{2\alpha}$) had been clearly delineated, considerable effort in the late 1970s and 1980s was spent characterizing the morphological and functional characteristics of the large and small steroidogenic cells. This was followed in the 1990s by increased interest in the roles that nonsteroidogenic cells, including endothelial cells, fibroblasts, pericytes and immune cells, might have in luteal function. It is now thought that the nonsteroidogenic cells are very active participants in regulating the functional capacity and lifespan of the CL. These cells communicate with the steroidogenic cells through the paracrine signaling molecules that they produce, and also through direct cell contacts. One form of direct cell-cell signaling that may serve to activate resident immune cells is major histocompatibility complex (MHC) molecule-dependent interaction between luteal cells with T lymphocytes. Expression of MHC molecules, and recognition of antigenic peptides presented in the context of MHC molecules, serves as a means to regulate the activation of T lymphocytes, thus controlling cytokine production and/or cytotoxicity.

Expression of MHC Molecules by Luteal Cells

Like the majority of other somatic cell types, luteal cells express class I MHC molecules. What is surprising is that

luteal cells of several species, including the cow, also express class II MHC molecules [1-5]. However, the identity of cells expressing class II MHC in the CL is somewhat in question. Class II MHC expression is typically limited to cells of the immune system that are regarded as "professional" antigen presenting cells, such as macrophages, dendritic cells, and to a lesser extent, B cells. Macrophages present within the CL would therefore certainly account for a percentage of the class II-positive cells. However, flow cytometric studies of dispersed bovine and ovine luteal cells demonstrated the presence of class II MHC molecules on both large and small cell populations [1,2], suggesting that, in addition to luteal macrophages (which would be included in the small cell fraction), the steroidogenic luteal cells also express class II MHC. Further, the bovine large luteal cell population was subdivided into two groups, large dense cells and large less-dense cells [1]. Both populations contain class II MHC-positive cells, but the large less-dense population contained the highest percentage of class II MHC-positive cells. The identity of the cells comprising these two populations is not known, but it is possible that one population represents the large steroidogenic cells, and the other population is composed of aggregates of luteal endothelial cells. A subpopulation of luteal endothelial cells expressing class II MHC has recently been identified [6].

In the human, luteinization induces the expression of class II MHC molecules on granulosa cells [7], and expression of both class I and class II MHC molecules increases on granulosa cells in the late luteal phase [3]. In contrast, minimal class II MHC expression is detected in developing bovine CL [1]. Class II MHC expression is

elevated in the bovine CL by midcycle, and in bovine and ovine CL, class II MHC expression is higher near the time of luteal regression compared with midcycle [1,2,5]. In contrast to the bovine and ovine CL, class II MHC expression in the equine CL is not elevated until after the decline in circulating progesterone concentrations associated with initiation of luteal regression [4]. Significantly, in each of these species, expression of class II MHC is substantially less in CL from pregnant animals compared with non-pregnant animals [1,2,4]. In the chicken, cells expressing class II MHC have been identified in the theca layer of normally growing and pre-ovulatory follicles [8,9]. The percentage of cells expressing class II MHC was greater in post-ovulatory follicles and atretic follicles compared with pre-ovulatory follicles, and class II MHC-positive cells are found in both the thecal and granulosa layers of post-ovulatory and atretic follicles [9].

Given the information available describing the expression pattern of class II MHC molecules in the CL, a role for class II MHC molecules in the process of luteal regression has been proposed. The increase in expression of class II MHC molecules between early and midcycle CL [1] coincides with the acquisition of luteolytic capacity. Expression of class II MHC molecules on the surface of luteal cells increases near the time of natural luteal regression and when luteal regression is induced by PGF_{2α} [1,5] but is lower in pregnant compared to non-pregnant animals [1,2,4]. From this observation it can be inferred that class II MHC expression must be attenuated as part of the mechanism that inhibits luteal regression during maternal recognition of pregnancy. In addition, bovine luteal cells stimulate T lymphocyte proliferation *in vitro*, and they are more potent stimulators of proliferation when derived from CL collected after administration of PGF_{2α} to the cow [10]. This indicates that there is a change in the character of luteal cells that enhances their ability to stimulate the activation of T lymphocytes.

A physiological role for MHC molecules in luteal function is supported by the observation that both class I and class II molecules are expressed by luteal cells *in vivo*, and the expression of class II molecules varies with functional state of the CL. These observations have given rise to the hypothesis that the demise of the corpus luteum may involve local autoimmune-response mechanisms facilitated by increased expression of cell surface class II MHC at the time of luteal regression.

Major Histocompatibility Complex Molecules, Antigen Processing, and Autoimmunity

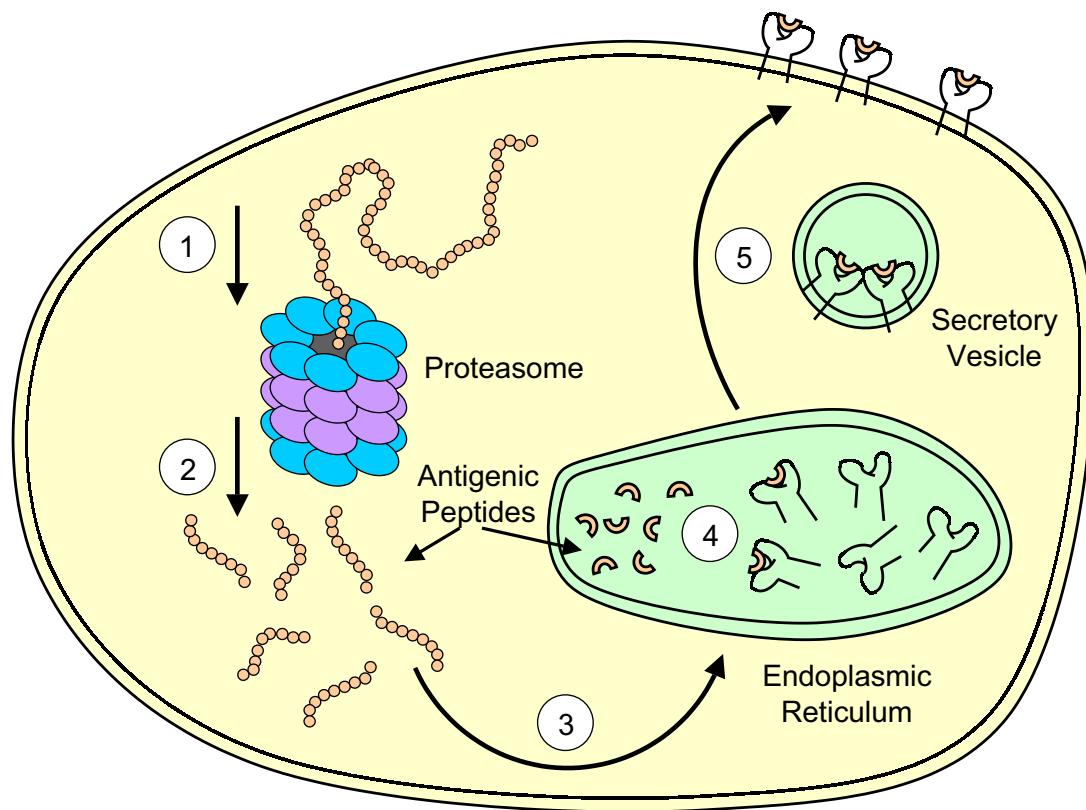
Stimulation of T lymphocyte activation is dependent on the specific interaction of a T cell receptor for antigen (TCR) on the T cell with MHC molecules located on the surface of the target cell [11]. The outcome of binding of

the TCR to the MHC molecule is determined by the peptides bound to the MHC molecules. In the context of T cell responsiveness to a given cell or tissue, changes in the array of MHC-bound peptides presented to T lymphocytes can determine whether T cells are activated by the MHC molecules in a given tissue, or alternatively, whether T cells will remain in an unactivated state, a condition known as immunological tolerance.

Antigenic peptides that are presented to T cells via MHC molecules are derived from proteins that are proteolytically digested into short peptides prior to binding to MHC molecules. Collectively, the proteolytic degradation of antigenic proteins and the binding of the resulting short peptides to MHC molecules is called antigen processing. Since antigen processing can determine the types of peptides bound to MHC molecules, this process can impact whether cells within a tissue are able to activate T lymphocytes, thereby stimulating an immune response.

Class I MHC

Processing of peptides for presentation in the context of class I MHC molecules is carried out by the proteasome. The proteasome is a cytosolic protease complex composed of multiple subunits that is responsible for the majority of intracellular protein turnover, and also generates peptides that are presented to T cells via class I MHC molecules (Figure 1; [12]). The catalytic core of the proteasome, referred to as the 20S proteasome, is composed of two heterologous families of subunits, termed α and β subunits. The proteasome β subunits contain the active proteolytic sites [13]. The composition of the 20S proteasome is balanced between expression of constitutive β subunits under normal conditions, and expression of IFN- γ -inducible subunits during inflammatory conditions. Interferon- γ induces the replacement of constitutively expressed β -subunits with alternative β -subunits involved in antigen processing [14-18]. The genes encoding two of these IFN- γ -induced subunits, LMP2 and LMP7, are located within the class II MHC gene region [19-21] and these subunits have limited homology to the constitutive subunits Y and X, respectively [14,22]. The third IFN- γ -inducible subunit, originally termed MECL-1 and also referred to as LMP10 [17], is similarly homologous to the constitutive β -subunit Z [23]. Thus, replacement of the constitutive β -subunits X, Y and Z with the IFN- γ -inducible subunits (LMP7, 2 and 10) alters the peptide cleavage patterns of the proteasome [24,25], resulting in alterations in the repertoire of antigenic peptides presented by class I MHC molecules. Interestingly, the IFN- γ -inducible subunits and their constitutive homologues seem to be reciprocally regulated. Tissues expressing high levels of LMP2, LMP7, or LMP10 were observed to have low levels of the constitutive homologous subunits [26]. Also, IFN- γ coordinately induces expression of LMP2, LMP7 and LMP10 with

**Figure 1**

Schematic representation depicting processing of antigens presented by class I MHC molecules. 1) Intracellular proteins are proteolytically degraded within proteasomes. 2) Proteolytic degradation of intracellular proteins yields antigenic peptides of nine to eleven amino acids. 3) Antigenic peptides generated by the proteasomes are transported into the endoplasmic reticulum. 4) Newly synthesized class I MHC molecules bind antigenic peptides within in the endoplasmic reticulum. 5) Class I MHC-antigenic peptide complexes are exported through the Golgi and to the cell surface, for presentation of antigenic peptide to CD8⁺ T cells.

concurrent reduction in expression of the constitutive homologues [17].

The most notable instance in which IFN- γ -inducible proteasome subunits are suspected to play a role in induction of an autoimmune response is autoimmune thyroiditis. The thyrocytes themselves appear to act as antigen presenting cells during the progression of the disease, stimulating the activation of T lymphocytes [27]. Studies of patients with Grave's disease and Hashimoto's thyroiditis, both of which are autoimmune thyroid disorders, found very high expression of LMP2 and LMP7 in the thyrocytes

themselves [28]. This implies that proteasomes in these cells generate peptides that, when bound to class I MHC molecules, stimulate the activation of CD8⁺ cytotoxic T lymphocytes, which infiltrate the thyroid tissue in massive numbers and exert cytotoxic effects on the thyrocytes [29].

We have recently demonstrated that interferon- γ -inducible subunits of the proteasome (mRNAs and protein) are expressed within the bovine corpus luteum [30]. Since bovine luteal cells isolated from regressing CL more potently stimulate T lymphocyte proliferation compared to luteal cells from midcycle CL [10], we hypothesized

that IFN- γ -inducible proteasome subunits would be upregulated in luteal tissue near the time of luteal regression. Such a change in proteasome subunit expression could induce alterations in the array of self-peptides presented to T cells in the context of class I MHC molecules during luteal regression, which could explain the enhancement in the ability of luteal cells to stimulate T cell activation following PGF_{2 α} administration. However, we discovered that LMP7 and LMP10 were expressed in the CL at all stages of the estrous cycle, with no upregulation following induction of luteal regression with PGF_{2 α} . No changes were observed in LMP7 expression throughout the estrous cycle, but LMP10 expression was less in early CL, and greater in midcycle and late CL [30].

Class II MHC

Class II MHC molecules, typically expressed on antigen presenting cells of the immune system (ie. macrophages, dendritic cells and B lymphocytes), bind short peptides derived from intracellularly processed proteins [31]. Class II MHC molecules are heterodimeric proteins composed of non-covalently associated α and β chains. Assembly of the class II MHC complex occurs within the endoplasmic reticulum (ER), and involves not only α and β chains, but a third, non-polymorphic glycoprotein called the invariant chain (Ii). As class II MHC molecules are synthesized, they immediately bind to Ii, a portion of which occupies the peptide binding groove of the MHC molecule [32]. Invariant chain serves a dual function, directing intracellular transport of class II MHC molecules [33,34] and ensuring that binding of "inappropriate" peptides does not occur prematurely [32]. The MHC class II-Ii complex is then transported into endosomes, in which proteolysis by cathepsins and lysosomal proteases degrade the Ii into a peptide called class II-associated invariant chain peptide (CLIP; [35,36]). Prior to binding of antigenic peptides by class II MHC molecules, the CLIP fragment bound to the peptide binding groove must be removed. A class II MHC-like heterodimeric protein generically referred to as DM co-localizes with class II MHC molecules in endosomal compartments [37] and catalyzes the removal of CLIP from the peptide binding groove of the class II MHC molecule [38,39]. Following CLIP removal, the class II MHC molecule is free to bind processed antigen, before transport to the cell surface (Figure 2). The ability to process and present antigen in a manner dependent on class II MHC can be conferred to non-antigen presenting cells by transfection with a class II MHC molecule, Ii, and DM. These appear to be minimal yet sufficient components required for reconstitution of the antigen processing machinery [40].

Numerous autoimmune diseases are associated with aberrant expression of class II MHC molecules, including insulin-dependent diabetes mellitus and autoimmune

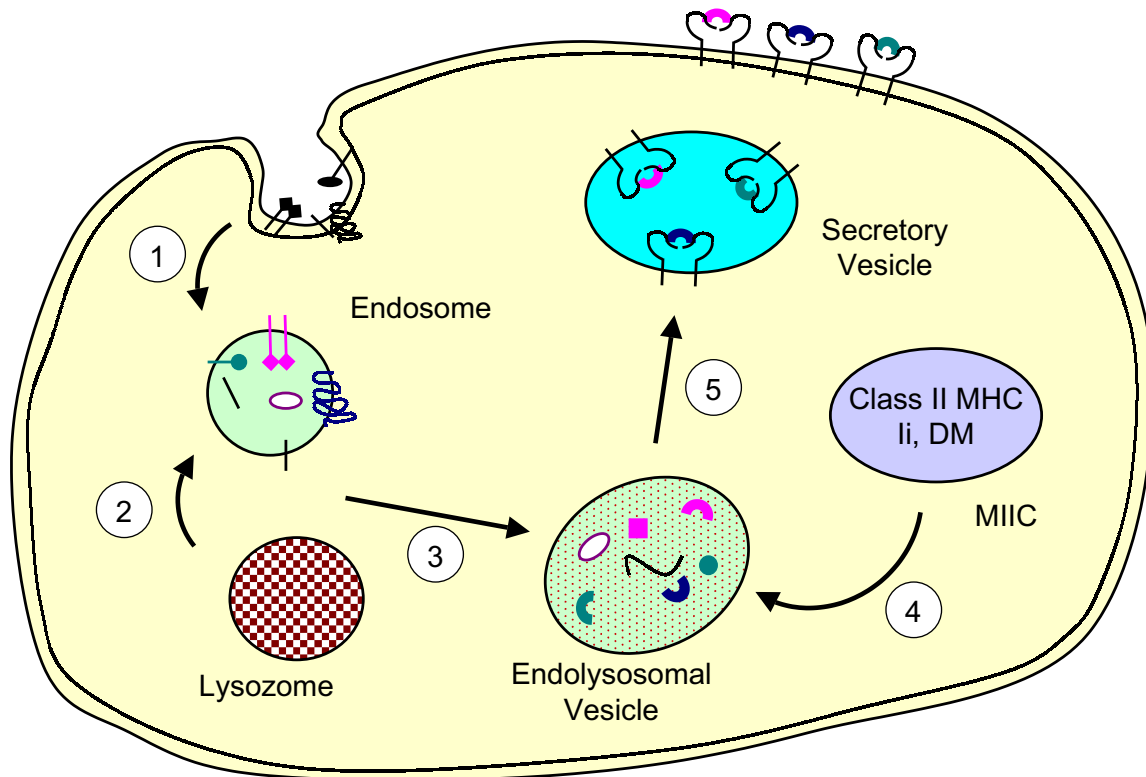
thyroiditis, which are endocrine autoimmune disorders. In these diseases, the target cells express Ii and DM molecules, indicating that they are acting as antigen presenting cells capable of stimulating activation of CD4⁺ T cells. Both Ii and DM mRNAs are expressed within bovine luteal tissue, with DM α and DM β being elevated in midcycle compared to early CL [41], and bovine luteal cells are potent stimulators of class II-MHC dependent T cell proliferation [10]. Therefore, cells within the CL are able to process and present antigens to T cells in the context of class II MHC, which may predispose luteal cells to an autoimmune-type MHC-mediated response during luteal regression.

The local inflammation that occurs concurrently with autoimmune diseases is often attributed to pro-inflammatory cytokines produced by T_{H1} cells. The mRNAs for several pro-inflammatory T cell-derived cytokines, and in some cases the proteins themselves, are present in the CL [5,42-46]. The presence of T cell-derived cytokines in luteal tissue suggests that the T lymphocytes present within the tissue are activated. Activated T lymphocytes produce IFN- γ and TNF- α , which increase expression of class I and class II MHC molecules on luteal cells, as well as inhibit progesterone production [47,48]. Thus, a positive feedback loop of antigenic peptide presentation and T cell activation could occur to facilitate the rapid demise of the tissue that occurs during luteolysis.

The Role of Costimulation In T Cell Activation

The presence of class I and class II MHC molecules on the surface of a cell allows the cell to interact with CD8⁺ and CD4⁺ T lymphocytes, respectively. However, there are two possible outcomes of MHC-mediated cellular interactions with T cells. In one instance, binding of MHC molecules to the TCR can occur in the absence of accompanying interactions between additional cell surface molecules. In this case an inactive state known as anergy will be induced in the T cells [49,50]. Induction of anergy is one means by which tolerance to antigens in peripheral tissues is induced, thus avoiding an autoimmune response [51]. Anergic T cells are prevented from carrying out their effector functions (cytokine secretion in the case of CD4⁺ T cells; cytotoxic activity in the case of CD8⁺ cells).

Alternatively, MHC-TCR ligation can occur in conjunction with a second interaction known as costimulation. Costimulatory signals are delivered to T cells by the cell surface proteins B7-1 and/or B7-2, also known as CD80 and CD86, respectively [52-54]. These ligands, when present on the antigen presenting cell surface, bind to the CD28 cell surface molecule on T cells and provide the costimulatory signal that promotes T cell survival [55] and induces T cell activation and clonal expansion [49,52,56], allowing the T cell to carry out its effector functions.

**Figure 2**

Schematic representation depicting processing of antigens presented by class II MHC molecules. 1) Extracellular and integral membrane proteins are internalized into endosomes via endocytosis. 2) Lysozomes fuse with endosomes. 3) Proteolytic degradation of endocytosed proteins occurs in the endolysosomal vesicle, resulting in the generation of antigenic peptides. 4) A specialized subcellular organelle containing the class II MHC molecules, invariant chain, and DM fuses with the endolysosomal vesicle. This results in proteolytic degradation of invariant chain to CLIP. DM then catalyzes removal of clip, and the empty class II MHC molecules then bind antigenic peptides. 5) Class II MHC-antigenic peptide complexes are then exported to the cell surface, for presentation of antigenic peptide to CD4⁺ T cells.

Therefore, while generation of sets of self-derived peptides capable of binding to MHC molecules and stimulating the activation of self-reactive T cells may predispose cells and tissues to an autoimmune response, the absence of a costimulatory signal can result in induction of tolerance to a tissue or cell type rather than activation of lymphocytes and induction of an immune response [57].

We recently demonstrated the expression of CD80 and CD86 in bovine luteal tissue. Similar to the pattern of DM α and DM β expression, steady-state concentrations of

CD80 and CD86 mRNA were greater in the bovine CL during midcycle as compared with early CL [58]. In functional studies, antibodies against CD80 or CD86 inhibited luteal cell-stimulated proliferation of T cells. These data indicate that bovine luteal cells express functional costimulatory molecules, which enable them to provide the costimulatory signal necessary for activation of T cells.

Conclusions

From the observation that expression of MHC molecules changes with functional state of the CL, it may be inferred

that these glycoproteins have a role in luteal physiology. Since class II MHC molecules increase during luteolysis and are suppressed during maternal recognition of pregnancy, it is likely that they are involved in luteal regression. Presentation of peptides in the context of MHC molecules would result in activation of T lymphocytes, with subsequent release of pro-inflammatory cytokines and cytotoxicity. Luteal tissue contains the intracellular proteins that are necessary for processing and presentation of antigenic peptides (LMP 7, LMP 10, Ii, DM), and the cell surface molecules necessary for costimulation (CD80, CD86) are also expressed. Further, these components are all apparently quite functional, since luteal cells are potent stimulators of T cell proliferation. Collectively, these events closely resemble those that occur in tissues undergoing autoimmune responses. Thus, we propose that the progression of luteolysis involves a localized autoimmune response involving MHC-mediated antigen presentation to T lymphocytes. The exact identity of the antigen-presenting cells is yet to be determined. Finally, it must also be recognized that the role of MHC molecules on luteal cells may be something other than to promote luteal regression. An alternative hypothesis is that MHC molecules are present in the CL to promote tolerance, particularly in the event of pregnancy. Clearly, the story of MHC molecules in the CL is just beginning to unfold.

Acknowledgments

Salaries and research support provided by National Institutes of Health grant HD37550 to JLP, and also by State and Federal funds appropriated.

References

1. Benyo DF, Haibel GK, Laufman HB, Pate JL: **Expression of major histocompatibility complex antigens on the bovine corpus luteum during the estrous cycle, luteolysis, and early pregnancy.** *Biol Reprod* 1991, **45**:229-23.
2. Kenny N, Herman JR, Barisas BG, Roess DA: **Flow cytometric analysis of class I and II MHC antigens on ovine luteal cell types.** In: *Signaling mechanisms and gene expression in the ovary* Edited by: Gibori G. New York, Springer-Verlag; 1991:467-472.
3. Bukovsky A, Caudle MR, Keenan JA, Wimalasena J, Upadhyaya NB, Van Meter SE: **Is corpus luteum regression an immune-mediated event? Localization of immune system components and luteinizing hormone receptor in human corpora lutea.** *Biol Reprod* 1995, **53**:1373-1384.
4. Lawler DF, Hopkins J, Watson DE: **Immune cell populations in the equine corpus luteum throughout the oestrous cycle and early pregnancy: an immunohistochemical and flow cytometric study.** *J Reprod Fertil* 1999, **117**:281-290.
5. Penny LA, Armstrong D, Bramley TA, Webb R, Collins RA, Watson ED: **Immune cells and cytokine production in the bovine corpus luteum throughout the oestrous cycle and after induced luteolysis.** *J Reprod Fertil* 1999, **115**:87-96.
6. Lehmann I, Brylla E, Sittig D, Spaniel-Borowski K, Aust G: **Microvascular endothelial cells differ in their basal and tumour necrosis factor- α -regulated expression of adhesion molecules and cytokines.** *J Vasc Res* 2000, **37**:408-416.
7. Khoury EL, Marshall LA: **Luteinization of human granulosa cells in vivo is associated with expression of MHC class II antigens.** *Cell Tissue Res* 1990, **262**:217-224.
8. Barua A, Yoshimura Y: **Immunolocalization of MHC-II⁺ cells in the ovary of immature, young laying and old laying hens *Gallus domesticus*.** *J Reprod Fertil* 1999, **116**:385-389.
9. Barua A, Michiue H, Yoshimura Y: **Changes in the localization of MHC class II positive cells in hen ovarian follicles during the**

processes of follicular growth, postovulatory regression and atresia. *Reproduction* 2001, **121**:953-957.

10. Petroff M, Coggeshall KM, Jones LS, Pate JL: **Bovine luteal cells elicit major histocompatibility complex class II-dependent T-cell proliferation.** *Biol Reprod* 1997, **57**:887-893.
11. Altman A, Mustelin T, Coggeshall KM: **T lymphocyte activation: a biological model of signal transduction.** *Crit Rev Immunol* 1990, **10**:347-391.
12. Rock KL, Goldberg AL: **Degradation of cell proteins and the generation of MHC class I-presented peptides.** *Annu Rev Immunol* 1999, **17**:739-779.
13. Tanahashi N, Tsurumi C, Tamura T, Tanaka K: **Molecular structure of 20S and 26S proteasomes.** *Enzyme Protein* 1993, **47**:241-251.
14. Akiyama K, Kagawa S, Tamura T, Shimbara N, Takashina M, Kristenson P, Hendil KB, Tanaka K, Ichihara A: **Replacement of proteasome subunits X and Y by LMP7 and LMP2 induced by interferon-gamma for acquisition of the functional diversity responsible for antigen processing.** *FEBS Lett* 1994, **343**:85-88.
15. Fehling HJ, Swat W, Laplace C, Kuhn R, Rajewsky K, Muller U, Von Boehmer H: **MHC class I expression in mice lacking the proteasome subunit LMP-7.** *Science* 1994, **265**:1234-1237.
16. Van Kaer L, Ashton-Rickardt PG, Eichelberger M, Gaczynska M, Nagashima K, Rock KL, Goldberg AL, Doherty PC, Tonegawa S: **Altered peptidase and viral-specific T cell response in LMP2 mutant mice.** *Immunity* 1994, **1**:533-541.
17. Nandi D, Jiang H, Monaco JJ: **Identification of MECL-1 (LMP10) as the third IFN- γ -inducible proteasome subunit.** *J Immunol* 1996, **156**:2361-2364.
18. York IA, Goldberg AL, Mo XY, Rock KL: **Proteolysis and class I major histocompatibility complex antigen processing.** *Immunol Rev* 1999, **172**:49-66.
19. Glynne R, Powis SH, Beck S, Kelly A, Kerr LA, Trowsdale J: **A proteasome-related gene between the two ABC transporter loci in the class II region of the human MHC.** *Nature* 1991, **353**:357-360.
20. Kelly A, Powis SH, Glynne R, Radley E, Beck S, Trowsdale J: **Second proteasome-related gene in the human MHC class II region.** *Nature* 1991, **353**:667-668.
21. Martinez CK, Monaco JJ: **Homology of proteasome subunits to a major histocompatibility complex-linked LMP gene.** *Nature* 1991, **353**:664-667.
22. Akiyama K, Yokota K, Kagawa S, Shimbara N, Tamura T, Akioka H, Nothwang HG, Noda C, Tanaka K, Ichihara A: **cDNA cloning and interferon gamma down-regulation of proteasomal subunits X and Y.** *Science* 1994, **265**:1231-1234.
23. Hisamatsu H, Shimbara N, Saito Y, Kristenson P, Hendil KB, Fujiwara T, Takahashi EI, Tanahashi N, Tamura T, Ichihara A, Tanaka K: **Newly identified pair of proteasomal subunits regulated reciprocally by interferon-gamma.** *J Exp Med* 1996, **183**:1807-1816.
24. Driscoll J, Brown MG, Finley D, Monaco JJ: **MHC-linked LMP gene products specifically alter peptidase activities of the proteasome.** *Nature* 1993, **365**:262-264.
25. Boes B, Hengel H, Ruppert T, Multhaup G, Koszinowski UH, Kloetzel PM: **Interferon gamma stimulation modulates the proteolytic activity and cleavage site preference of 20S mouse proteasomes.** *J Exp Med* 1994, **179**:901-909.
26. Stohwasser R, Stander S, Peters I, Kloetzel PM, Groettrup M: **Molecular cloning of the mouse proteasome subunits MC14 and MECL-1: Reciprocally regulated tissue expression of interferon-gamma-modulated proteasome subunits.** *Eur J Immunol* 1997, **27**:1182-1187.
27. Weetman AP: **Autoimmune thyroid disease: propagation and progression.** *Eur J Endocrinol* 2003, **148**:1-9.
28. Vives-Pi M, Vargas F, James RF, Trowsdale J, Costa M, Sospedra M, Somoza N, Obols G, Tampe R, Pujol-Borrell R: **Proteasome subunits, low-molecular-mass polypeptides 2 and 7 are hyperexpressed by target cells in autoimmune thyroid disease but not in insulin-dependent diabetes mellitus: implications for autoimmunity.** *Tissue antigens* 1997, **50**:153-163.
29. Martin A, Barbésino G, Davies TF: **T-cell receptors and autoimmune thyroid disease - signposts for T-cell-antigen driven diseases.** *Int Rev Immunol* 1999, **18**:111-140.
30. Cannon MJ, Pate JL: **Expression and Regulation of Interferon γ -Inducible Proteasomal Subunits LMP7 and LMP10 in the Bovine Corpus Luteum.** *Biol Reprod* 2003, **68**:1447-1454.

31. Sant AJ: **Endogenous antigen presentation by MHC class II molecules.** *Immunol Res* 1994, **13**:235-267.
32. Roche PA, Cresswell P: **Invariant chain association with HLA-DR molecule inhibits immunogenic peptide binding.** *Nature* 1990, **345**:615-618.
33. Bakke O, Dobberstein B: **MHC class II-associated invariant chain contains a sorting signal for endosomal compartments.** *Cell* 1990, **63**:707-716.
34. Lotteau V, Teyton L, Peléaux A, Nilsson T, Karlsson L, Schmid SL, Quaranta V, Peterson PA: **Intracellular transport of class II MHC molecules directed by invariant chain.** *Nature* 1990, **348**:600-605.
35. Maric MA, Taylor MD, Blum JS: **Endosomal aspartic proteinases are required for invariant chain processing.** *Proc Natl Acad Sci USA* 1994, **91**:2171-2175.
36. Riese RJ, Wolf PR, Bromme D, Natkin LR, Villadangos JA, Ploegh HL, Chapman HA: **Essential role for cathepsin S in MHC class II-associated invariant chain processing and peptide loading.** *Immunity* 1996, **4**:357-66.
37. Sanderson F, Kleijmeer MJ, Kelly A, Verwoerd D, Tulp A, Neefjes JJ, Geuze HJ, Trowsdale J: **Accumulation of HLA-DM, a regulator of antigen presentation in MHC class II compartments.** *Science* 1994, **266**:1566-1569.
38. Morris P, Shaman J, Attaya M, Amaya M, Goodman S, Bergman C, Monaco JJ, Mellins E: **An essential role for HLA-DM in antigen presentation by class II major histocompatibility molecules.** *Nature* 1994, **368**:551-554.
39. Fling SP, Arp B, Pious D: **HLA-DMA and -DMB genes are both required for MHC class II/peptide complex formation in antigen-presenting cells.** *Nature* 1994, **368**:554-558.
40. Karlsson L, Peléaux A, Lindstedt R, Liljedahl M, Peterson PA: **Reconstitution of an operational MHC class II compartment in nonantigen-presenting cells.** *Science* 1994, **266**:1569-1573.
41. Cannon MJ, Pate JL: **Presence and steady-state amounts of mRNA encoding class II MHC antigen processing proteins in bovine luteal tissue during the estrous cycle and PGF_{2α}-induced regression.** *Biol Reprod* 2000, **62**(suppl 1):144.
42. Roby KF, Terranova PF: **Localization of tumor necrosis factor (TNF) in the rat and bovine ovary using immunocytochemistry and cell blot: evidence for granulosa production.** In: *Growth factors and the Ovary* Edited by: Hirshfeld AN. New York, Plenum Press; 1989:273-278.
43. Bagavandoss P, Wiggins RC, Kunkel SC, Remick DG, Keyes PL: **Tumor necrosis factor production and accumulation of inflammatory cells in the corpus luteum of pseudopregnancy and pregnancy in rabbits.** *Biol Reprod* 1990, **42**:367-376.
44. Ji I, Slaughter RG, Ellis JA, Ji TH, Murdoch WJ: **Analyses of ovine corpora lutea for tumor necrosis factor mRNA and bioactivity during prostaglandin-induced luteolysis.** *Mol Cell Endocrinol* 1991, **81**:77-80.
45. Shaw DW, Britt JH: **Concentrations of tumor necrosis factor alpha and progesterone within the bovine corpus luteum sampled by continuous-flow microdialysis during luteolysis in vivo.** *Biol Reprod* 1995, **53**:847-854.
46. Petroff MG, Petroff BK, Pate JL: **Expression of cytokine messenger ribonucleic acids in the bovine corpus luteum.** *Endocrinology* 1999, **140**:1018-21.
47. Fairchild DL, Pate JL: **Interferon-γ induction of major histocompatibility complex antigens on cultured bovine luteal cells.** *Biol Reprod* 1989, **40**:453-457.
48. Benyo DL, Pate JL: **Tumor necrosis factor-α alters bovine luteal cell synthetic capacity and viability.** *Endocrinology* 1992, **130**:854-860.
49. Gimmi CD, Freeman GJ, Gribben JG, Sugita K, Freedman AS, Morimoto C, Nadler LM: **B cell surface antigen B7 provides a costimulatory signal that induces T cells to proliferate and secrete interleukin 2.** *Proc Natl Acad Sci USA* 1991, **88**:6575-6579.
50. Chen C, Nabavi N: **In vitro induction of T cell anergy by blocking B7 and early T cell costimulatory molecule ETC-1/B7-2.** *Immunity* 1994, **1**:147-154.
51. Lechler R, Chai J-G, Marelli-Berg F, Lombardi G: **The contributions of T-cell anergy to peripheral T-cell tolerance.** *Immunology* 2001, **103**:262-269.
52. Freeman GJ, Boriello F, Hodes RJ, Reiser H, Gribben JG, Ng JW, Kim J, Goldberg JM, Hathcock K, Laszlo G, Lombard LA, Wang S, Gray GS, Nadler LM, Sharpe AH: **Murine B7-2, an alternative CTLA4 counter-receptor that costimulates T cell proliferation and interleukin 2 production.** *J Exp Med* 1993, **178**:2185-2192.
53. Guerder S, Picarella DE, Linsley PS, Flavell RA: **Costimulator B7-1 confers antigen-presenting-cell function to parenchymal tissue and in conjunction with tumor necrosis factor α leads to autoimmunity in transgenic mice.** *Proc Natl Acad Sci USA* 1994, **91**:5138-5142.
54. Lenschow DJ, Walunas TL, Bluestone JA: **CD28/B7 system of T cell costimulation.** *Ann Rev Immunol* 1996, **14**:233-258.
55. Boise LH, Minn AJ, Noel PJ, June CH, Accavitti MA, Lindstein T, Thompson CB: **CD28 costimulation can promote T cell survival by enhancing the expression of Bcl-x_L.** *Immunity* 1995, **3**:87-98.
56. Linsley PS, Brady W, Grosmarie L, Aruffo A, Damle NK, Ledbetter JA: **Binding of the B cell activation antigen B7 to CD28 costimulates T cell proliferation and interleukin 2 mRNA accumulation.** *J Exp Med* 1991, **173**:721-730.
57. Flavell RA, Hafler DA: **Autoimmunity. What is the turning point?** *Curr Opin Immunol* 1999, **11**:635-637.
58. Cannon MJ, Pate JL: **Presence and steady-state amounts of mRNA encoding costimulatory molecules CD80 and CD86 in bovine luteal tissue during the estrous cycle and PGF_{2α}-induced luteal regression.** *Biol Reprod* 2001, **64**(suppl 1):287.

Publish with **BioMed Central** and every scientist can read your work free of charge

"BioMed Central will be the most significant development for disseminating the results of biomedical research in our lifetime."

Sir Paul Nurse, Cancer Research UK

Your research papers will be:

- available free of charge to the entire biomedical community
- peer reviewed and published immediately upon acceptance
- cited in PubMed and archived on PubMed Central
- yours — you keep the copyright

Submit your manuscript here:
http://www.biomedcentral.com/info/publishing_adv.asp

